D4.1 Algorithm Theoretical Baseline Document – SAR Mode Coastal and Open Ocean Data Products produced by ESRIN

1. INTRODUCTION

This document describes the algorithms used by Salvatore Dinardo and Bruno Lucas (both of ESRIN) to generate a set of CryoSat-2 SAR Data Products for Application over the Coastal and Open Ocean, using the SAMOSA echo model. This document has been compiled by David Cotton (SatOC) based on information from SD and BL.

2. OVERVIEW

Table 1 lists the set of CryoSat-2 SAR data products that were generated by ESRIN (and NOC) using the SAMOSA echo model for open and coastal ocean applications:

Run Reference	***C2 L1B Product***	***L2 SAR retracker model***	***Alpha-p LUT***	***Peel Effect applied***	***Motivation***
ESRIN R1	CPP	ESRIN SAM2	Yes	Yes	Full SAMOSA analytical model (Guassian waves statistics
NOC R2	CPP	NOC SAM3	No	No	Consistent with Sentinel 3 DPM except for treatment of Thermal Noise. Only small data set available for benchmarking
ESRIN R3	CPP	ESRIN SAM3	Yes	Yes	To quantify impact on retrieval of omitting f1 term in SAMOSA3
ESRIN R4	CPP	ESRIN SAM3	Yes	No	Consistent with Sentinel 3 DPM but with inclusion of alpha_p LUT
ESRIN R5	ESRIN FBR	ESRIN SAM2	Yes	Yes	Possible impact of L0 – > L1B processing
ESRIN R6	CPP	ESRIN SAM3	No	No	Consistent with Sentinel 3 DPM baseline

Table 1: Summary of SAR L2 Data sets produced using the SAMOSA echo model.

All except the NOC R2 data products are generated for the Pacific and NE Atlantic SAR regions, and for the months July 2012 and January 2013. The S3 DPM is described in Reference 1.

The data product analysed in the Impact Assessment (WP5000) is ESRIN R1. All of the data sets in Table 1 are assessed in the Coastal Ocean Product Validation report produced by NOC.

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3. ALGORITHM DESCRIPTION

The general processing approach for SAR (Delay Doppler) L1b is described in Reference 2.

This document deals with the generation of Level 2 data from Level 1b. The following standards were applied:

- The Reference Time for the TAI Datation is 01/01/2000 00:00:00

- The Vertical Datum for altitude reference is the Topex/Poseidon Ellipsoid
- The SAR Return Power Model is SAMOSA (reference 3)
- If the SAMOSA2 model is se with Gaussian PTR approximation corrected by the usage of Look-up Table
- The Curve Best-Fitting Scheme is a Bounded Levenberg-Marquardt Least-Squares Estimation Algorithm (LEVMAR-LSE)
- No Static bias has been applied to the range, wave height and sigma nought measurements / Static bias has been applied to the range, wave height and sigma nought measurements - the values of the static biases are reported in the output NetCDF data products
- The Doppler Shift Correction has been applied to the range measurements
- The internal path delay has been not applied to the range measurements
- The orbital altitude has not been corrected for the Time Tag Bias / The orbital altitude has been corrected for a Time Tag Bias. The value of the applied time tag bias is reported in the output NetCDF data products.
- The measurements are posted either 20 Hz and 1 Hz rate
- Geo-corrections (not available in input CPP L1b products) and sea state bias correction have not been applied.
- No a priori editing has been applied to the 20 Hz measurements
- The misfit between SAR Waveform Model and SAR Waveform Data has been computed as:

sqrt(1/128(residuals).^2)*100*

where residuals are the differences between model's waveform power and data's waveform power, normalised for the waveform power's maximum value

The residuals have been computed ruling out from the data's and model's waveform return power the first 12 and last 12 range bins (CPP standard).

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Table 2 (from Reference 4) lists the L2 processing options applied with the SAMOSA echo model:

SAMOSA Retracking Scheme (L2) Processing Options	
RIR used to compute the Doppler model	Gaussian Function, α_p **dynamically extracted at real time from LUT**
AIR used to compute the Doppler model	Gaussian Function, α_p **dynamically extracted at real time from LUT**
Peeling of the Delay Doppler Map (DDM)	APPLIED
Thermal Noise Handling	In input to the re-tracking scheme and measured from SAR Echo's early samples
Mis-pointing Handling	Mis-pointing angles in input to the retracking scheme and read from CPP products
Multi-looking Handling	Multi-looked Echo Model built accumulating the same number of looks as accumulated at L1b stage to build the data waveform
Waveform Normalization	Applied with a moving window size of 1 range bin (i.e. normalization by waveform absolute maximum)
Input Waveform Sub-setting	NOT APPLIED
SAMOSA Model Generation	SAM3 or SAM2
Skewness Effect	NOT APPLIED
Scattering Amplitude Decay Rate (nu)	set to zero
Slope (Orbital and Surface) Effect	NOT APPLIED
Re-tracking Algorithm	Bounded Levenberg–Marquardt Least Square Estimator (LEVMAR-LSE)

Table 2: SAMOSA L2 Processing Options

Below are provided further details on how to:

- build and apply the α_p look-up table (LUT) for the SAMOSA 3 Model
- "peel-off" the SAMOSA-3 Delay Doppler Map

3.1 Building α_p Look Up Table: Methodology and Application

The α_p LUT is built and applied following the steps listed below:

- for each SWH value in input (SWH ranging between 0.1 meter and 10 meter) and for a fixed epoch value (zero), the numerical SAMOSA model and the analytical SAMOSA 3 model are generated using **exactly the same radar parameter and geometrical configuration**.
- the α_p table is built finding, for each SWH in input, the α_p value providing the best fit, **in rms error term,** between the SAMOSA numerical model and the SAMOSA 3 analytical model.
- The α_p LUT is applied in **real time**, (i.e. during the re-tracking algorithm execution), extracting, from the table, the α_p value corresponding to the SWH value under iteration.

The calculated α_p LUT values are provided in Annex A.

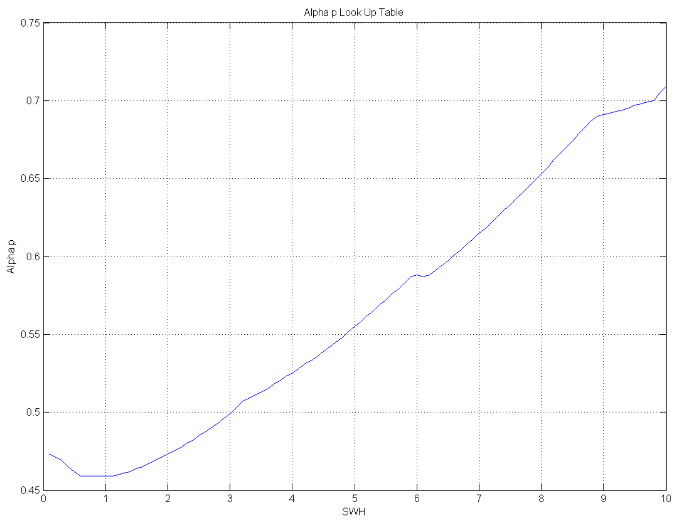

Figure 1: Look Up Table for alpha p

3.2 Application of the Delay Doppler Map Peel-Off

The SAMOSA model assumes the existence (on board of CryoSat-2) of a radar tracker with an unlimited (or very long) size for the receiving window. This is not the case for a typical realization of a space-born radar altimeter. The consequence of a limited size of the tracker

window is that, during the slant range correction stage, the Data Stack samples are padded with zeroes and these zero-samples are summed up along with signal samples (not-zeroes) during the L1b multi-looking operation. In order to cope with this operating procedure carried out along the CryoSat-2 L1b Chain, a SAMOSA-3 DDM peeling operation has been proposed before to apply the multi-looking at L2.
The zeroes are placed in the SAMOSA-3 Delay Doppler Map following the methodology described below:

- The delay range of each range gate k in a generic Delay Doppler Map column l (i.e. Delay-Doppler beam) is calculated as:

$$\delta r_k = \frac{c_0}{2 \cdot B_r}\left[N_s - 1, -1, 0\right] \quad \text{with } k = 1,..,128$$

- The slant range shift of each beam in the Delay Doppler Map is calculated as:

$$\delta R_l = H \cdot \left(\sqrt{1 + \alpha_E \cdot \left(\frac{L_x \cdot (l)}{H} \right)^2} - 1 \right) \quad \text{with } l = -32,..,31$$

- For each DDM column l, zeroes are placed in range gates (k,l) for which holds the relation:

$$\delta r_k \le \delta R_l \quad \text{with } k = 1,..,128$$

with the notation:

c_0	vacuum speed light
B_r	Received Bandwidth
N_s	Number of Range gates (128)
H	Orbital Altitude
L_x	Along Track Resolution
α_E	Earth Sphericity Factor
l	Along Track Beam Index (-32->31)
k	Range Gate Index (1 -> 128)

where [a,s,b] represents an array from a to b with step s.
An instance of pseudo-code statements implementing the proposed process can be:

```
R=Height.*(sqrt(1+(alpha_E.*(Lx.*(l)./Height).^2))-1);
R=repmat(R,Ns,[]);
Dr=repmat(c0./(2.*Br)*(Ns-1:-1:0),[],size(l,2)).';
DDM(R>=Dr)=0;
```

4. GLOSSARY

ATBD	Algorithm Theoretical Baseline Document
CPP	CryoSat Processing Prototype
CS2	CryoSat-2
DDM	Delay Doppler Map
DPM	Detailed Processing Model
FBR	Full Bit Rate CryoSat-2 SAR mode data ((un-calibrated, geo-located I and Q individual echoes in time domain)
LEVMAR-LSE	Levenberg-Marquardt Least-Squares Estimation
LUT	Look Up Table
NOC	National Oceanography Centre, Southampton UK
PTR	Point Target Respose
PVR	Product Validation Report
SAMOSA	SAR Altimetry Mode Studies and Applications (SAR altimetry project funded under the ESA STSE programme
SAM2	Simplified version of SAM3 to enable more efficient computation.
SAM3	Full analytical model of the SAR altimeter ocean waveform, developed in the SAMOSA project
SAR	Synthetic Aperture Radar
STSE	Support to Science Element
SWH	Significant Wave Height
S3	Sentinel-3

5. REFERENCES

Reference 1: Detailed Processing Model of the Sentinel-3 SRAL SAR altimeter océan waveform retracker (latest version) – Available on request from Jérôme Benveniste (ESA/ESRIN)
Reference 2 : Guidelines for the SAR (Delay-Doppler) L1b Processing, ESA, 2013, available here
Reference 3: SAR Altimeter Backscattered Waveform Model (SAMOSA Model Paper), IEEE-TGARSS, in press
Reference 4: Configuration Control Document for CP40ers who retrack CPP Data, ESA, 2014 (available here)

ANNEX A

α_p Look Up Table

The α_p values for the proposed LUT are reported in the below table for each SWH value:

SWH	Alpha_p
0.1	0.473
0.2	0.471
0.3	0.469
0.4	0.465
0.5	0.462
0.6	0.459
0.7	0.459
0.8	0.459
0.9	0.459
1	0.459
1.1	0.459
1.2	0.460
1.3	0.461
1.4	0.462
1.5	0.464
1.6	0.465
1.7	0.467
1.8	0.469
1.9	0.471
2	0.473
2.1	0.475
2.2	0.477
2.3	0.480
2.4	0.482
2.5	0.485
2.6	0.487
2.7	0.490
2.8	0.493
2.9	0.496
3	0.499
3.1	0.503
3.2	0.507
3.3	0.509
3.4	0.511
3.5	0.513
3.6	0.515
3.7	0.518
3.8	0.520
3.9	0.523
4	0.525
4.1	0.528
4.2	0.531
4.3	0.533
4.4	0.536
4.5	0.539
4.6	0.542
4.7	0.545
4.8	0.548
4.9	0.552
5	0.555
5.1	0.558
5.2	0.562
5.3	0.565
5.4	0.569
5.5	0.572
5.6	0.576
5.7	0.579
5.8	0.583
5.9	0.587
6	0.588
6.1	0.587
6.2	0.588
6.3	0.591
6.4	0.594
6.5	0.597
6.6	0.601
6.7	0.604
6.8	0.608
6.9	0.611
7	0.615
7.1	0.618
7.2	0.622
7.3	0.626
7.4	0.630
7.5	0.633
7.6	0.637
7.7	0.641
7.8	0.645
7.9	0.649
8	0.653
8.1	0.657
8.2	0.662
8.3	0.666
8.4	0.670
8.5	0.674
8.6	0.679
8.7	0.683
8.8	0.687
8.9	0.690
9	0.691
9.1	0.692
9.2	0.693
9.3	0.694
9.4	0.695
9.5	0.697
9.6	0.698
9.7	0.699
9.8	0.700
9.9	0.705
10	0.709

For values out of the SWH range [0.1 10] meter, it is proposed to use the α_p value corresponding to the nearest tabulated SWH value.